MANAGEMENT OF THE CEREAL LEAF BEETLE PEST ECOSYSTEM

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INTRODUCTION

The development of an effective pest management program must rely on basic biological knowledge about the pest and its environment. Even with a minimum amount of information modelling of the systems can progress. These initial attempts at modelling are extremely useful in directing research toward specific model oriented objectives. In the past, without the guiding influence of these systems models, the tendency, in some cases, has been to obtain more information than was actually needed for useful predictions while some areas of research have been totally neglected.

A great deal of effort has been expended in developing optimal methods of quantitative population description through time of all life stages of the cereal leaf beetle (*Oulema melanopus* (L.)), its small grain hosts and its introduced parasites. The acquisition of detailed biological parameters for the cereal leaf beetle began in 1967 and is continuing at the present time at Michigan State University. Systems modelling efforts were not initiated until 1971, and it is clear now that this work should have started simultaneously with the population studies.

With the present forms of the model, sensitivity analyses have given additional insight into the biological behavior of the system. The modelling effort is beginning to help guide our biological research activities by indicating, through sensitivity testing of parameter values, where biological research efforts should be directed. The models indicate areas where biological information is weak and the particular areas which need more accurate investigation.

However, one of the principal factors limiting the usefulness of these predictive models is our inability to obtain real-time information about the pest-crop system. Since the vast majority of populations in pest ecosystems are keyed to a time-temperature function, we are not in a position to use artificial constraints or long term averages, but must work with the climatic and biological data as it unfolds during the periods when various management strategies can still be implemented. If pest management programs are to effectively use the advantages of ecosystem modelling, there must be considerable improvement in both collecting and processing biological and climatic information on the state of the pest ecosystem.

THE CEREAL LEAF BEETLE COMPONENT

Distribution

In North America, the cereal leaf beetle, is now distributed over a very large area which increases every year. It is primarily a pest of spring grains, but can cause damage to winter grains, and survive on many species of grass. The damage to all hosts is most severe during warm, dry springs – when oviposition and larval development proceed rapidly and plant growth is reduced. In dry years, total loss of spring grains are possible if chemical sprays are not used.

Life Cycle

The cereal leaf beetle overwinters as an adult in forest litter, grass crowns, grain stubble, under bark and generally in any site well protected from temperature extremes. In Michigan, adults emerge in April, and after a few days, begin feeding on native grasses, winter grains and eventually spring grains. The females mate after spring feeding and mate intermittently through the ovipositional period, from mid-April to June. Females prefer to lay their eggs singly on the upper surface of the leaf along the mid-vein, near the base. Larvae generally feed on the upper leaf surface and when development is complete will drop or crawl to the ground and enter the soil to pupate. New adults emerge and feed in late June on available grasses for several weeks. After this initial feeding period the new adults enter a state of reduced activity and are found with increasing frequency in overwintering sites.

Research History

A considerable amount of time has been spent studying the cereal leaf beetle since its discovery in 1962. The research has followed a rather natural evolution for an introduced economic pest. The early studies had as their objective eradication before the beetle population could spread beyond the initial point of introduction. American entomologists were not familiar with the life history and had to spend a considerable amount of time studying its basic life cycle along with insecticide screening and application timing studies. When chemical control methods were available the information was passed on to government agencies who attempted wide-area applications of pesticides for the purpose of eradication.

By 1964, there were two other major facets of the work. One dealt with host plant resistance and the other with quarantines. A team effort was started to isolate resistant wheat varieties. By 1967, the majority of the world's seed bank for wheat had been screened. A form of resistance was found that was closely associated with the degree of leaf pubescence. This resistance is available now but has not been incorporated into any commercial varieties of wheat.

The second aspect of work initiated in 1964 was a search for effective quarantine measures. The problem was to determine which crops needed to be restricted in their movement and how they could be cleared. A cooperative state quarantine effort was undertaken with limited success. Each year the quarantine line was extended approximately 75 to 100 miles until now it includes most of the United States east of the Mississippi River.

By 1966, it was clear that the cereal leaf beetle could not be stopped with chemical control methods or quarantine methods. The emphasis in the research began to shift and new programs were started in the area of nutrition, basic behavioral studies, and population dynamics. An efficient and effective rearing program was established so that beetles were available for research throughout the year. Though the rearing program was successful in many respects, the program's principal objective of finding a synthetic lure was totally negative. At present we still have no way to attract these insects to traps, nor have we any idea of what stimulates them to feed on oats or wheat.

Radiation methods for sterilization have proven ineffective. The dosage required to sterilize an adult is extremely close to the dosage which is lethal. Plant resistance did not prove to be an easily or readily available control method. Other than the leaf pubescence, no form of resistance has been found in wheat, and no effective resistance has been found in other grains.

We seem to be at the point where there is general acceptance of the idea that the control of this insect will be through a program of pest management. A keystone to this type of program is the research on the population dynamics of cereal leaf beetle undertaken at Michigan State University.

Population Studies

A study on the population dynamics of the cereal leaf beetle was initiated in 1967 at Michigan State University. During the seven generations we have studied this insect, our principal objectives have been to develop sampling techniques of known reliability for all life stages of the cereal leaf beetle, to measure the influence of introduced biotic control agents, and to measure (natural) environmental resistance encountered, such as climate and host plants. We have made a particular effort to follow the population systematically as it spreads in North America to obtain a permanent detailed record of this introduced pest to test future theories of population regulation. The cereal leaf beetle represents only one pest of a long list of inevitable introductions that will take place in the future. What we learn with this insect will have vast implications for treatment of this type of problem, which surely will occur with increasing frequency in the future. In general, our approach has been to use a life table as a rough guide to collect the initial information from which our first models have been constructed.

One of the most difficult aspects of studying the cereal leaf beetle has been the greatly overlapping life stages. During June, there are eggs, 1st, 2nd, 3rd, and 4th instar larvae present in the field all at one time. This required us to develop techniques to study populations with heavily overlapped age intervals. We shall continue this work in the future. Peripheral to this study in population dynamics we have developed a great many tools and analytical methods for describing and sampling the population. Our sampling techniques for estimating population densities have been tested under field conditions and have proven to be reliable and efficient. We know how to sample and maintain a pre-determined sample error. We have developed mechanical methods for separating pupae and adults from the soil and techniques for accurately estimating total egg-input into a given field.

By comparing the integrated area under a total incidence curve of each life stage, we have developed a model of within-generation survival which explains to a large part the variation observed in mortality over a wide range of densities. We found that survivorship in the eggs, 2nd instar, and 3rd instar is a constant. However, survivorship in the 1st and 4th instar varies predictably with cereal leaf beetle density and with host plant. Mortality of pupae, adult survival and fecundity are not predictable and seem to be related to unpredictable climatic factors.

THE PARASITE COMPONENT

The search for effective biological control agents was begun in Europe during 1963 by the United States Department of Agriculture. At the present time, four species have been established in Michigan: the egg parasite *Anaphes flavipes* (Foerster), *Tetrastichus julis* (Walker) a gregarious larval parasite, and the solitary ichneumon *Diaparsis carinifer* (Thomson). During the 1972 field season, the fourth larval parasite, *Lemophagus curtus* (Townes), became established. In 1970, *A. flavipes* and *T. julis* reached a level at our field station where we could begin to develop a model of their mode of action.

Each of these parasites seems to have unique characteristics which will have a pronounced influence on the management of the cereal leaf beetle. The egg parasite *Anaphes* seems to have excellent dispersal qualities and an extremely high reproductive potential. However, it is poorly synchronized with that portion of the cereal leaf beetle population that occurs in wheat and reaches its highest attack rates in late planted oats. It appears that it will have a negative influence on cereal leaf beetle control since our population model for within-generation survival shows that as beetle egg density is decreased larval survival is increased in the first and fourth instars. *Anaphes* seems to have the potential of greatly reducing the survival of hosts occurring late in the season, but it is in direct competition with the larval parasite *T. julis.*

T. julis has two generations a year, a very high reproductive potential and a relatively low dispersal quality. It is better synchronized with its host than *Anaphes* and attacks larvae on both wheat and oats. We were able to increase the number very rapidly over three years in one 40 acre site, but until 1972 it was very scarce ¼ mile away in each direction. We have concluded from this that it has a relatively low dispersal characteristic. This is neither good nor bad. From the standpoint of management, keeping parasites localized in the area they were produced has considerable advantage. In these concentrated areas, they can be protected, moved, manipulated, or provided resources to overcome some inherent inefficiency. It is also very appealing to a grower who realizes that the damage his crop has sustained will be compensated somewhat by having higher parasitization the following year in the nearby fields.

Because this parasite has low mobility, we will be able to select different strategies to manipulate its influence on the cereal leaf beetle. However, *T. julis* had one factor acting against it before we even started measuring its influence. It must compete with *A. flavipes* for the late cereal leaf beetle larvae which it uses to overwinter. All late larvae are attacked, and adult *T. julis* are still present in the field after the cereal leaf beetle larvae have all pupated. The eggs killed by *Anaphes* did not produce late larvae for *T. julis* to attack. Its rate of increase is greatly reduced by this competition. With the greater mobility of *Anaphes*, it appears that this interaction will be a major consideration in any management program for the cereal leaf beetle.

It is difficult to see how this competitive relationship could have anything but a negative influence in any control strategy. We have a case here where a very poor parasite, from the standpoint of its potential to regulate its host numbers, competes directly with a parastie with many desirable characteristics that are very amenable to management. *T. julis* is exposed to over 80 percent of the host population, remains as a local population, and its rate of increase is controlled by availability of late larvae.

The success of *Anaphes* as a viable population will be at the expense of *T. julis*, not the survival of *T. julis* but its rate of increase. Perhaps we are not too far from the time when we will be looking for a control method for parasite populations.

THE HOST PLANT COMPONENT

As our modelling efforts evolved, we realized that it was unrealistic and wasteful of resources to attempt to regulate a pest population at a particular density considered below the level of economic damage. Damage is a function of insect feeding and host plant response. The year to year tolerance of a small grain crop varies considerably. Optimally, we would like to maximize the number of cereal leaf beetles in an area below a threshold density where economic damage will occur. We are attempting to develop a dynamic model allowing us to predict an economically tolerable pest density within the environmental constraints of plant growth. This phase is relatively difficult and is receiving much of our attention at present. If parasites can reduce the cereal leaf beetle to very low levels, the question of damage is inconsequential, but at present it appears to be an essential component. Our objective is to develop a model that handles a varying damage threshold in response to a varying insect population regulated by parasites and cultural procedures.

Plant dynamics can influence the dynamics of an insect like the cereal leaf beetle at different levels of interaction. In Michigan, due to various economics and climatic factors, oat production in a given region can vary from year to year in excess of two orders of magnitude. If we measure a trend index or population change from one generation to the next and the acreage of oats is doubled over this same period of time the cereal leaf beetle population will appear to remain the same on a per acre basis when in fact, it has doubled. There is a dynamic and significant interaction between field density and the measured insect density.

Wheat is more consistently planted than oats due to our present economic planning. Acreages are relatively constant on a time scale by varying on a spatial scale to the same degree as oats. Neither oats nor wheat is planted as a continuous rotation and the cereal leaf beetle cannot return to the same field in the spring from where it was produced the preceding summer.

To understand the population dynamics of the cereal leaf beetle it is important to understand the dynamics of grain fields both on a spacial and temporal scale.

Host plants can interact with the cereal leaf beetle population on still another level. Individual fields have specific characteristics such as planting date, rate of maturity and spatial distribution. As the cereal leaf beetle moves through the grain fields it tends to remain where it finds succulent growth. The younger the growth at the time of the initial attack the more severe will be the crop damage. In Michigan the usual situation is for spring grain to sustain heavy damage relative to winter grains, which are much taller at the time of initial attack. It is possible for late fall planted winter grains to come through the winter as a very young plant with little more than the plant crown alive. Under these conditions the cereal leaf beetle does not leave the wheat fields but remains and continues to feed throughout the entire growth period of the plant. Adjacent oat fields receive much less damage and the wheat crop can be lost. This situation was observed at Gull Lake, Michigan in 1970.

Plant-insect interactions occur at yet another level. Individual plant growth is the principal dynamic component of larval mortality at various densities within a field. In this interaction the plant induces changes in the insect population and the insect population causes changes in the plant. It is possible to apply liquid fertilizers to wheat at the optimal time and increase insect survival and therefore density but also reduce plant damage.

The plant at any time during its growth phase represents a standing crop available to the cereal leaf beetle but as well its growth represents potential future food for the insect. Growth potential interacts with insect density in a non-linear manner. After the cereal leaf beetle density within a field reaches a certain critical threshold the plant ceases its growth function and rapidly reaches senescence. This greatly intensifies the density dependent mortality in the cereal leaf beetle population and the grain crops appear to turn from a green crop to a dead crop over a two day period.

At this point it is clear that the dynamics of fields and individual plants are equally as complex as that for the population of the cereal leaf beetle and that the beetle population interacts at each level of environmental organization either in a real sense or as we perceive the situation when monitoring the population.

DESCRIPTION OF THE CEREAL LEAF BEETLE PEST ECOSYSTEM

The life system of the cereal leaf beetle is complex and is closely tied to the physical environment, as well as to the dynamic components of both the parasite population and the growth of the host plant. For example, adult beetles are extremely mobile and at one time or another have about equal probability of being found on any square foot of the terrestrial environment. Spring adults seem to move in a directed manner, responding to environmental cues, and leave larval populations behind which are separated in distinct increments of time and space. Parasite populations each year must initiate their activity from the locations of last year's beetle population because they overwinter in the soil. The adult beetles must discover new fields each year and they should not be expected to distribute themselves among these fields in equal proportions. Further, the parasites in search of hosts in these same fields will have a distribution different from the cereal leaf beetle.

Host damage is a function of beetle density and their own inherent growth capacity, influenced by climatic factors and cultural practices. Conventional agricultural practices in grain production destroys over 95 percent of the parasite population with soil tillage while these same practices have no effect on the cereal leaf beetle population. The plant response to the damage caused by very high beetle densities can vary from zero reduction in yield to total crop destruction. The largest difference in plant response to a constant beetle density occurs between years but the between field and within field differences can be highly significant.

The real management program must be more than a series of recommendations to bring about a particular change in a pest population. It must also include evaluation of the implementation of these recommendations and a determination of the ultimate population response. Even if we had total understanding of a biological system like that involving the cereal leaf beetle we still must implement an effective pest management program. Figure 1 is a block diagram illustrating how pest management models could be integrated into an operational on-line pest management system.

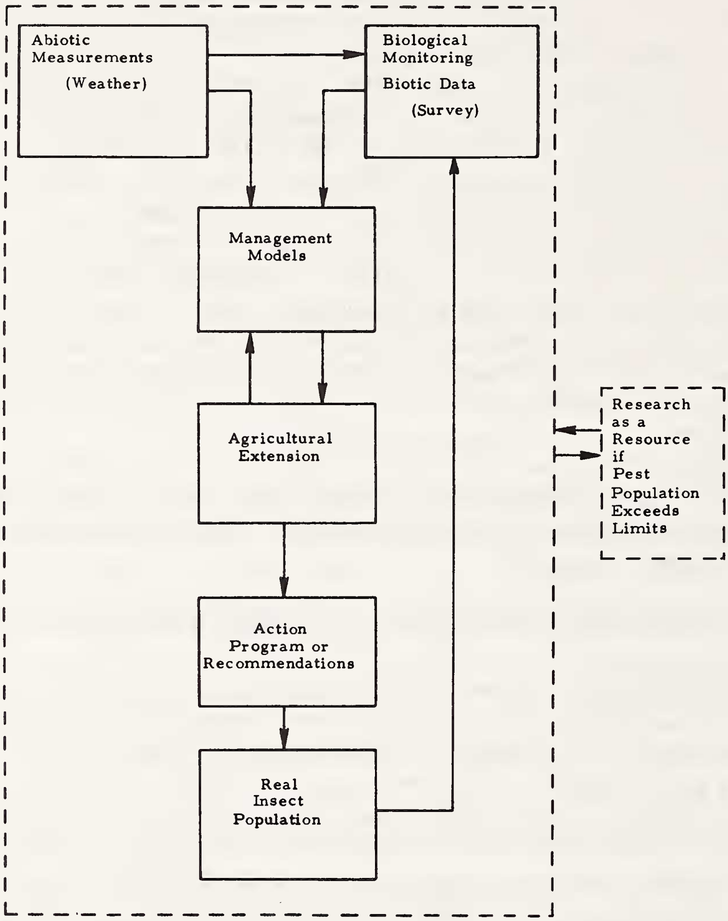


Fig. 1. Block diagram illustrating the basic components of a fully operational on-line pest management system.

Our initial objective in developing a systems model for the cereal leaf beetle is to gain insight into the fundamental control mechanisms that operate within the system. With this understanding a model will allow for the screening of management strategies without the high cost of implementation. These screened strategies are useful but cannot be confused with the actual pest management program. A particular strategy must be tested and thoroughly evaluated before it can be incorporated into a management program. Models are generally used for predicting long and short range population trends. In both cases, the precision of the model determines the accuracy of population predictions compared to the real population. The need for long range accuracy justified the previous emphasis on precision of the model. However, if we can economically update the parameters of the population model several times a year then it should not be necessary to obtain the precision in the model that would be required to simulate for long periods of time. In general there are two distinct uses for a systems model. One is the screening of various combinations of control practices to make optimum a control program, and the second is to answer questions that arise today about tomorrow's optimum control activity.

Basically our problem has been to quantify the significant interactions between the host plant, the cereal leaf beetle population, four parasite populations and the physical environment. The functional components of the cereal leaf beetle ecosystems are shown in Figure 2. Figure 2 represents our approach to the cereal leaf problem and is useful in planning biological research. The specific models help us establish priorities in the utilization of our rather limited financial support for conducting research and to estimate the degree of accuracy required in our measurements. These models are being improved constantly with new biological observations and checks on accuracy. The limiting factor in using population models in a management program is obtaining real-time or current information about abiotic and biotic variables (Haynes *et.al.*, 1973). With a given set of these variables (mean temperature, solar radiation, moisture, pest density, etc.) we will be able to improve our prediction of the outcome of a particular interaction between the cereal leaf beetle, its small grain host plant and the parasite population.

An Illustration of On-Line Pest Management.

I would like to illustrate the concepts of on-line pest management by briefly discussing only a small part of the total cereal leaf beetle ecosystem modelling program. This illustration is based on information obtained by a quantitative examination of interaction between the cereal leaf beetle and its principal introduced parasite, *Tetrastichus julis*. In southern Michigan, cereal leaf beetle adults, which have emerged from their overwintering sites in woodlots, along fence rows, etc., are found laying eggs in winter wheat in late April. Later, as spring oat seedlings begin to emerge from the soil, the adult beetles move to the younger, more succulent oat plants preferring them for feeding and also for egg laying. When the soil begins to accumulate heat above 48°F in the spring, parasite larvae, overwintering in last year's small grain stubble, begin development. After sufficient heat is accumulated, parasite adults emerge and disperse to attack cereal leaf beetle larvae which are feeding on the leaves of the current small grain crop.

An adult parasite lays about five eggs in each cereal leaf beetle larva attacked. These parasite larvae grow slowly within the cereal leaf beetle larva until the cereal leaf beetle larva has finished feeding on the leaves of the crop, and drops to the soil to pupate. As soon as a pupal cell is formed by the cereal leaf beetle, the parasites grow rapidly and kill and consume the cereal leaf beetle before it develops into an adult. Some of the parasites develop into adults and attack cereal leaf beetle larvae still in the crop, whereas others remain as larvae inside the cereal leaf beetle pupal cell as diapausing parasites that will not emerge until the following spring. The relationship between *T. julis* and the cereal leaf beetle can be seen in Figure 2. (Figure 2 denotes the life cycle of the beetle-parasite complex.)

The important point is that this system is dependent on meteorological events, especially temperature, as it relates to development and maturation of the populations. For example, Figure 3 shows the emergence of adult parasites from oat stubble (first parasite generation) and from the oat crop (second parasite generation) measured during 1971, 1972 and 1973 in one locality. Note that by manipulating the soil temperature using different techniques, emergence of the adult parasites can be advanced or retarded. Emergence information is useful in

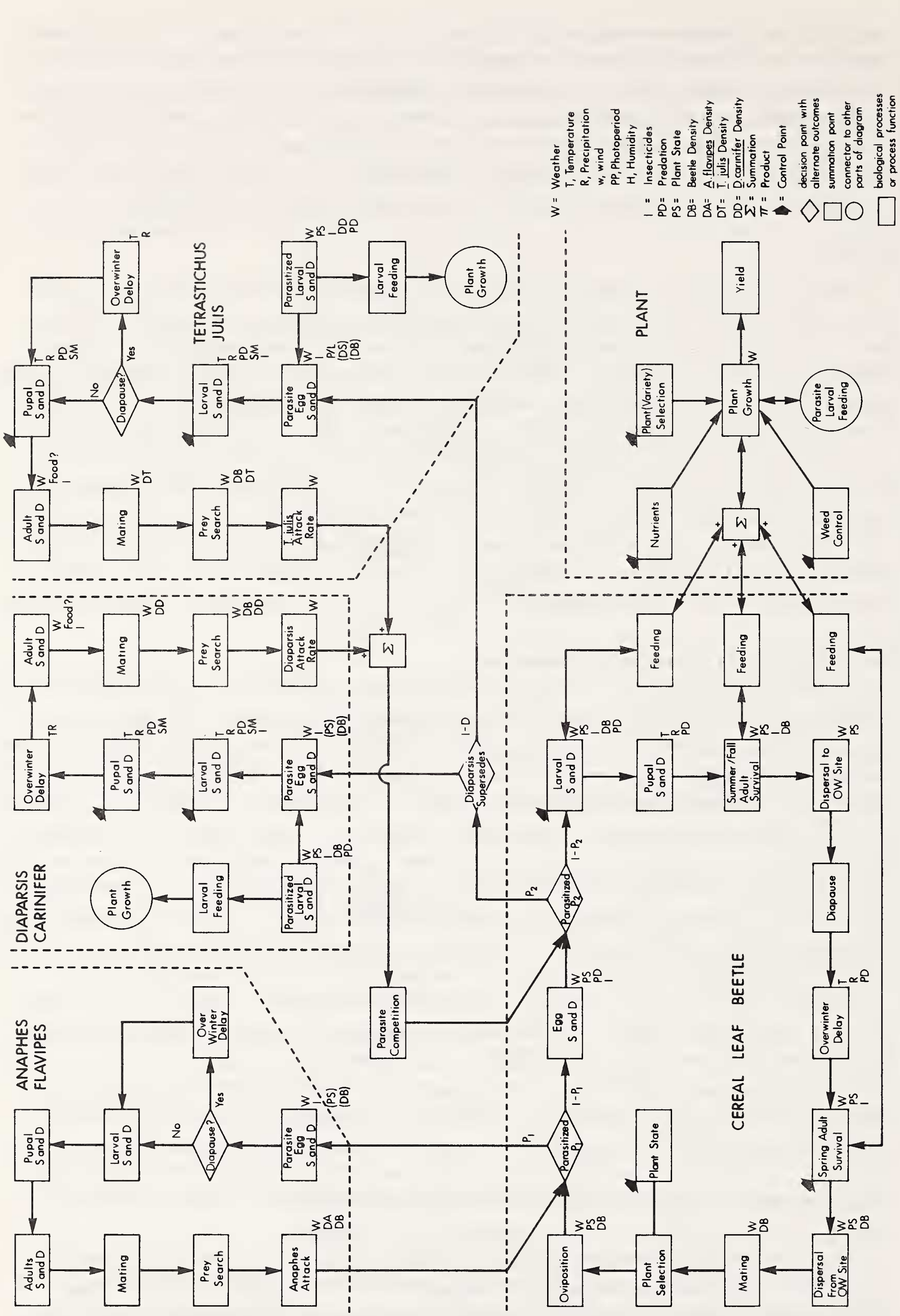


Fig. 2. A functional representation of the cereal leaf beetle ecosystem. (Blackbox representation of pest ecosystem model.)

the locality where it is measured to predict when the parasites will be present in the fields. If control of the beetle populations using pesticides is necessary, spraying during the time when the parasite is operating can then be avoided. One example would be to spray prior to initial emergence of the parasites from oat stubble (> 300 °D) with the aim of directing mortality against the adult beetles ovipositing in the crop. This "biological window" is predictable locally, but on a state or regional basis the ability to guess the occurrence of this window (when the maximum numbers of beetle adults are in the field prior to parasite emergence) is next to impossible.

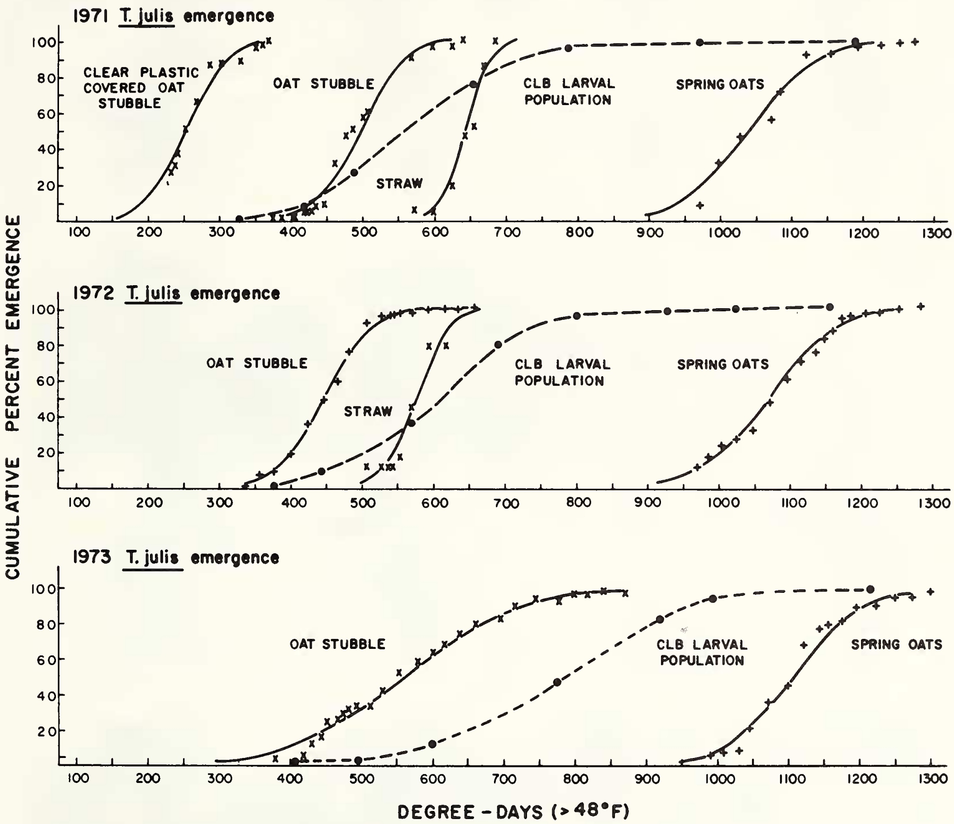
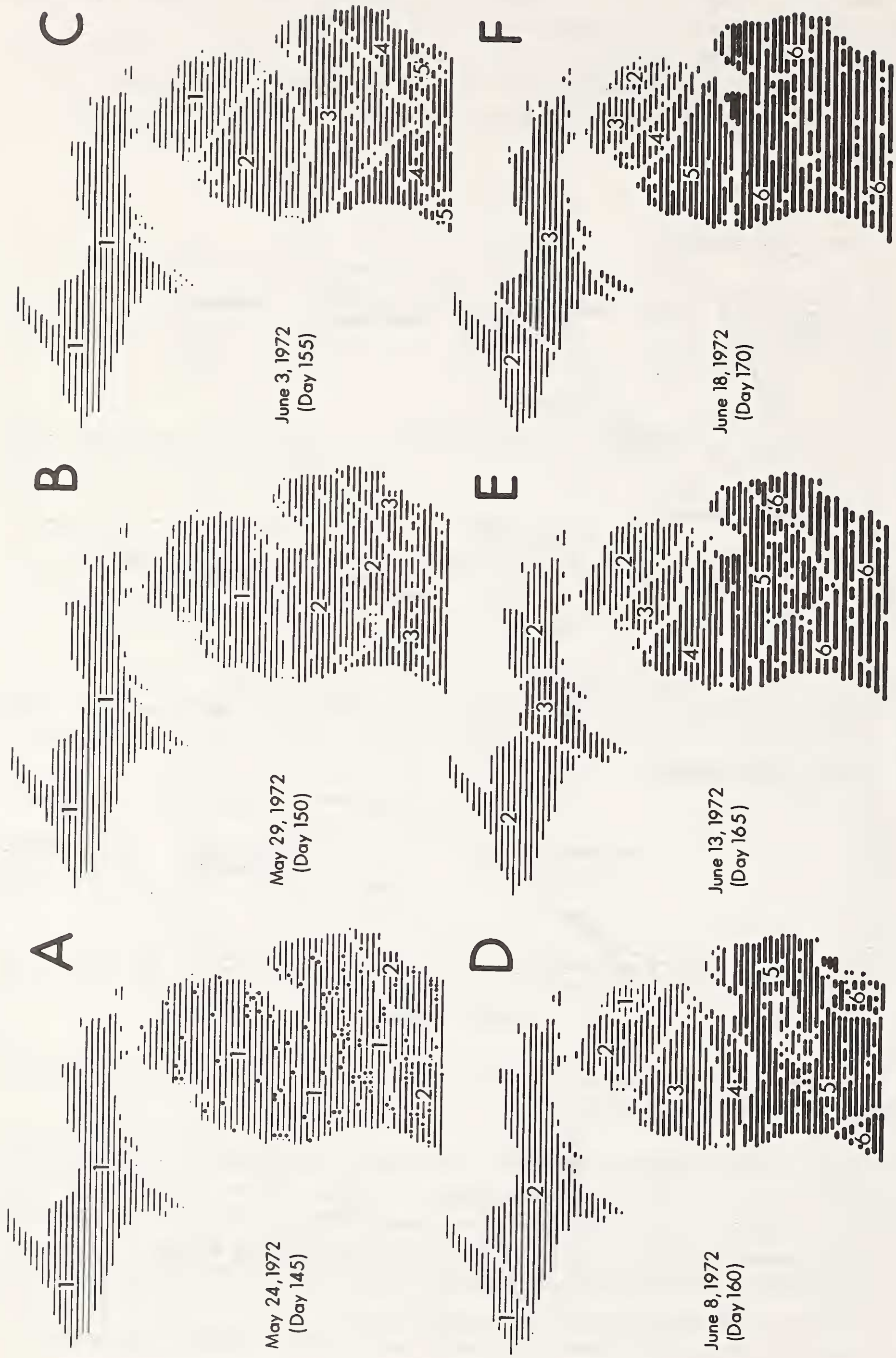


Fig. 3. The emergence curves of the spring and summer generations of different treatment on emergence. The dashed line represents the cereal leaf beetle larval population.

To illustrate this concept, the parasite emergence from oat stubble in the spring was subdivided into six levels representing the degree-day interval at different points along the emergence curve. Figure 4 (legend) shows the percent cumulative emergence and the degree-day interval representing this emergence class. To use this information for Michigan, degree-days were accumulated above the developmental threshold of the parasite (48°F) from daily minimum and maximum temperatures obtained from eighteen airport weather stations in the state. Figure 4 shows the dispersal throughout the state of each parasite emergence class at five-day intervals in 1972.


A
May 24, 1972
(Day 145)
B
May 29, 1972
(Day 150)
C
June 3, 1972
(Day 155)
D
June 8, 1972
(Day 160)
E
June 13, 1972
(Day 165)
F
June 18, 1972
(Day 170)

LEGEND

	Emergence class (°D_{48})	% cumulative emergence
1	0 - 373	0 - 5
2	374 - 452	6 - 25
3	453 - 505	26 - 50
4	506 - 557	51 - 75
5	558 - 637	76 - 95
6	above 638	96

Fig. 4. The distribution of 6 levels of emergence of the spring generation of *T. julis* at 5 day intervals from day 145 to day 185 of 1972. Location of sampling stations for Figs. 4 (A-I) are shown as dots on Fig. 4A.

LITERATURE CITED

Haynes, D. L., R. K. Brandenburg and P. D. Fisher. 1973. Environmental monitoring network for pest management systems. Environmental Entomology. 2 (5): 889-899.